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Special Section Guest Editorial: Detectors for Astronomy and Cosmology

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Astronomers are dreaming up fantastic measurements to understand our universe using platforms varying from ground based to suborbital to CubeSats and SmallSats, all the way to giant aperture telescopes orbiting Earth. While no one instrument component is clearly more essential than the others (what is a telescope without the optics or the mechanical structures to point it?), the guest editors of this detector-themed section of JATIS (split between the October-December 2019 and January-March 2020 issues) are eager to accept the often-repeated statement (by detector experts) that detectors are the heart of any astronomical instrument. It is noteworthy that instrument designs meant to push current measurement capabilities to their limits are often based on the limitations or advantages of existing detectors. This has less to do with any "essential" quality and more to do with the relative effort needed to develop new detector technologies or even achieve incremental improvements. In the short-term, while it is not always easy to improve signal-to-noise by adjusting instrument specifications such as optics or observing strategy, these are typically preferable to inventing a lower noise detector. In the long term, with each new detector advancement, the instrument trade space expands, allowing more design flexibility or enabling previously unattainable measurements.

Having obtained a detector with precisely the desired combination of sensitivity, pixel scale, format, power consumption, readout options, and cost—that is to say, a unicorn—the work is not yet done. In the era of precision astronomy, science reach is often limited by poorly understood detector behavior. In cosmological surveys, where the number of sources can reach into the billions, statistical errors are averaged down to levels below detector-induced systematic errors. Exoplanet measurements using the radial velocity technique may require detecting spectral shifts comparable to the silicon lattice spacing of the CCD! Successful campaigns thus require not only state-of-the-art detectors but also advanced knowledge of how to operate and calibrate detectors effectively for a particular science case. The *Image Sensors for Precision Astronomy (ISPA)* workshop, held at Caltech in December of 2018, was dedicated to this theme. We are grateful to the ISPA attendees who contributed to this section, especially Pierre Antilogus, who contributed the workshop introduction.

In the infrared, the paper by Cabrera et al. details the development of 15 μm cutoff infrared arrays, which will enable wide-area searches for near-Earth objects with NEOCam. The arrays are based on the popular HgCdTe detectors from Teledyne Imaging Systems and will thus benefit from the work of various other groups who are taking deep dives into understanding the systematics of this family of devices. The paper by Ninan et al. demonstrates a model and correction for the "crosshatch"—a high-frequency pattern of quantum efficiency variations on subpixel scales that can degrade high-precision measurements such as radial velocities of exoplanet systems. Meanwhile, Donlon et al. provide a new correction scheme for inter-pixel capacitance, a form of crosstalk between adjacent pixels that is crucial to understand for precision measurements sensitive to the point spread function. Crosstalk also couples amplifier channels in these infrared detectors, complicating the effect far beyond adjacent pixels. Thankfully, George et al. provide a fast method to measure and correct the coupling between all detector channels. These papers demonstrate the important role that detector users are playing in IR detector development.

Moving to the other end of the spectrum, Kyne et al. push the limits of detector sensitivity toward ultraviolet by upgrading the detector of FIREBall—a balloon-borne instrument that measures UV emission around galaxies—to a delta-doped electron-multiplying CCD (EMCCD). Optimized for a narrow atmospheric window for a balloon (190–215 nm), the UV-enhanced photon counting detector contributed greatly to improvement in sensitivity relative to the previous FIREBall design while removing high voltage requirement. Gleisinger et al. use the same model of EMCCDs to measure UV quantum yield—a challenging but essential calibration now that CCDs are being used in the far UV. Characterizing quantum yield with a photon counting CCD cleverly decouples the measurement from the device's quantum efficiency and provides a window into the physics of photon transfer. As silicon UV detectors become more widely used for astronomy, particularly in space-based instruments, the need for better characterization will grow.

Several authors remind us there is still much to learn even from mature devices like CCDs. Snyder and Roodman take an in-depth look at charge-transfer inefficiency (CTI) in CCDs developed for the Large Synoptic Survey Telescope (LSST). Beyond the CTI effect incurred with each pixel transfer, they find additional contributions possibly due to charge trapping and an electronic offset drift. Park et al. characterize the "tree ring" pattern of astrometric distortions in the same CCDs, quantifying the length scale and amplitude of the pattern as a function of wavelength and back bias voltage. Also for LSST, Juramy et al. investigate "tearing patterns" in CCD flat fields. In addition to mitigating the effect by changing how they operate the CCDs, they provide insight into the physics of the effect, theorizing that parallel clocking is moving positively charged holes into regions around channel stops. Creative CCD clocking can also be used to solve issues originating outside the detector, such as thermal instability, as shown by Blake et al. By shifting charge within a pixel during exposures, they are able to mitigate temperature variations in the NEID spectrograph, which aims to detect line shifts of a few nanometers on the focal plane. Finally, Weatherill et al. take a closer look at the origins of correlated double sampling (CDS) noise and, by analyzing an oversampled video signal, derive an optimal CDS timing scheme. In these instances, valuable insights come from researchers with high precision needs pushing beyond the typical use cases for their devices.

As astronomical measurements come to require more precision and sophistication, detector characterization must evolve to match. Often, subtle detector behavior goes unnoticed in conventional testing, only becoming apparent later in the astronomical data analysis, at which point mitigation schemes are limited. The paper by Vorobiev et al. describes a precision spot scanner designed for characterization of intra-pixel response variations, which contribute to photometric uncertainties in e.g., exoplanet detection. Using a spot less than 3.5 microns wide, they generate detailed, multiwavelength response maps of a Kepler CCD. In addition to investigating known detector issues, it is important to also uncover the "unknown unknowns" that may undermine scientific measurements. The paper by Shapiro et al. argues for the importance of characterizing detectors by projecting realistic images onto sensors and performing analyses that allow one to validate both the detector performance and the calibration strategy for challenging science cases. They provide an overview of the Precision Projector Laboratory, a flexible testbed designed for this purpose, which has investigated detector issues for JWST, WFIRST, Euclid, and other projects. Similarly, Christov et al. describe the development of a flexible new characterization setup that will allow sensors to be tested with a range of stimuli, including various light sources, image patterns, and an x-ray source.

Detectors are particularly easy to admire when showcased as part of new instruments. For instance, the 3 gigapixel focal plane of LSST consists of 21 autonomous "Raft Tower Modules," each housing 9 CCDs. O'Connor presents characterization results for these modules, which themselves have strict mechanical and electro-optical requirements to meet the speed and sensitivity needs of LSST. Another ambitious instrument, the Palomar Radial Velocity Instrument (PARVI), aims to use a near infrared spectrograph (resolution $\sim$100,000) to detect exoplanets from radial velocity signals as low as 30 cm/s (i.e., the star moves at the speed of crawling). As described in the paper by Gibson et al., PARVI is enabled in part by a guider based on the InGaAs C-RED 2 camera from First Light Advanced Imagery. The camera, operated at −40C and clocking 400 FPS, is used in a tip-tilt loop to keep starlight centered on the spectrograph fiber, making low noise a crucial feature.

The papers in this special section give us a glimpse of the powerful impact of detectors on astronomy. They illustrate how state-of-the-art detectors are enabling exciting new science, and they highlight work that must be done to bring them to their full potential. Advancements that lead to the next great discoveries will surely include new detectors as well as improved understanding of existing ones. We thank all of our contributors and wish them, and the readers, best of luck in their endeavors in the exciting days ahead in astronomy and astrophysics.